SOIL FAUNA AND AGRICULTURE: PAST FINDINGS AND FUTURE PRIORITIES

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ABSTRACT

General findings of soil: soil fauna research are given under the headings of soil pests, effects of beneficial soil animals, and effects of agricultural practices. Arguments are presented for a sustainable agriculture and for a more rational approach to problem solving within agroecosystems. The use of indicators of agroecosystem distress is advocated. Comments are included on research needs and implementation of sustainable systems of soil management.

RÉSUMÉ

Les découvertes générales de la recherche sur les sols et leur faune sont présentées sous les en-têtes d'organismes nuisibles, d'effets des animaux bénéfiques aux sols, et d'effets des pratiques agricoles. L'auteur offre des arguments en faveur d'une agriculture soutenable et d'une approche plus rationnelle pour résoudre les problèmes dont souffrent les agro-écosystèmes. Il préconise l'utilisation d'indicateurs de stress dans les agro-écosystèmes et commente sur les besoins en recherche et sur la mise en oeuvre de systèmes soutenables d'aménagement des sols.

INTRODUCTION

Agriculture is defined as the science or practice of cultivating the soil and rearing animals, and cultivation as the preparation, tillage and use of soil to produce crops. Because definitions aim to clarify and simplify meaning, they often perpetuate destructive myths that are harder to change than the definitions that incorporate them. The above definitions, for example, paint a picture of a linear agriculture with a black box, the soil, in the middle. The farmer stirs up the soil with a tool, sows seeds and harvests the plants that mysteriously grow. At first the system was thought to be limited to people, land, seeds and tools. More recently, synthesized fertilizers and pesticides have been added to the equation. These and other developments have led to an agriculture that is characterized by large parcels of land being kept bare for most of the year, often only one crop species being grown year after year, and production being maintained through a heavy reliance on imported seeds, energy as fuel for equipment, fertilizers and pesticides. The outcome has been increased dependence, environmental stress and a loss of capital from the system in terms of crop cultivars, soil and nutrients, water, natural controls of pests, and other beneficial organisms.

Studies of the relationships between soil fauna and agriculture0have been conducted within such systems. They comprise three types of studies: (1), of pest species and their control; (2), of beneficial species and their effects; and (3), of the effects of agricultural practices on soil animals. Because of the difficulties of studying organisms in a stratified opaque medium that is complex in terms of its physical, chemical and biological parameters, and that varies in time and space, progress in all of these areas have been limited. Some general statements, however, can be made. Useful reviews are provided by Kevan (1962), Edwards and Lofty (1969), Mills and Alley (1973), Wallwork (1976), and in the Proceedings of the Colloquium edited by Dindal (1980). As most of the following statements are of a general nature or are based on personal observation and/or on the soil fauna literature in general, they are not supported by specific references. These are, however, given where useful reviews or landmark papers are known to exist, or where particular points need to be stressed.

SOIL PESTS

1. Soil pests are at least as significant, in terms of economic damage, as above ground pests.
2. Pesticides, because of difficulties of distribution in soil, adsorption and decomposition, have provided less effective control in soil than above soil.
3. The biology and ecology of most soil pests is inadequately understood and relatively few biological controls have been exploited.
4. The use of cultural methods (crop rotation, use of intercrops, timing of operations, soil and habitat management) and resistant crop varieties, if available, are essential for the control of soil pests.

EFFECTS OF BENEFICIAL SOIL ANIMALS

1. All soil animals have beneficial effects on soil structure and fertility.
2. Although their direct effects on processes such as soil formation and organic matter decomposition are small in comparison with those of microorganisms, their indirect and catalytic effects are substantial and essential. These include the improvement of food and space conditions for microorganisms and higher plants, selective cropping and transportation of microorganisms, aeration, drainage, biological control of pests and soil mixing. Generally, their role should be seen as one of "regulation" rather than the simple acceleration of soil processes, which is a common misconception. (Macfadyen, 1961, 1963; Weetman *et al.*, 1972; Hill *et al.*, 1973; Behan and Hill, 1978; Lee, 1979; Anderson *et al.*, 1981; Luxton, 1982; Parkinson, 1983; Seastedt and Crossley, 1984).
3. Most studies of the contribution of soil animals have failed to deal with the soil system as a functional whole. Rather, they have focused on isolated groups and processes. Consequently our views of how the soil works is still very fragmentary.
4. Few attempts have been made to introduce and manage beneficial soil fauna (Edwards 1981). Developments in this area will eventually lead, together with parallel developments in other areas, to the redesign of our food producing systems and to changes in our approach to soil management.

EFFECTS OF AGRICULTURAL PRACTICES

1. Dominant agricultural practices (tillage, clean cultivation, monoculture, row crops, use of pesticides and certain synthetic fertilizers) simplify the soil community and reduce the beneficial contribution of soil animals (Edwards and Lofty, 1969; Edwards and Thompson, 1973; Andrén and Steen, 1978; Edwards, 1983). Manures and most fertilizers generally increase numbers and species of soil animals (Marshall 1977).

2. Although numerous studies have been carried out on these effects they have not led to any changes in agricultural practices - the beneficial soil fauna remains a largely unknown and untapped resource within the food system.

3. Preliminary studies have indicated the value of using the presence and population density of certain soil animals as indicators of soil conditions (Karg, 1968).

4. The growing concern with soil degradation and interest in miminum tillage and ecological approaches to agriculture are causing some attention to be focussed on the soil fauna (Stinner and Crossley, 1983). The questions that are being raised provide soil ecologists with an important opportunity to make practical contributions to the design of sustainable food systems.

SUSTAINABLE AGRICULTURE

As responsible scientists we have an important role to play in the evolution of a sustainable lifestyle for our species. Because of its increasing dependence on distant non-renewable and renewable resources, and its heavy environmental impact, modern agriculture is clearly not sustainable.

Systems of agriculture that have increased "productivity" (to satisfy markets manipulated through advertising), "profit" and "power" as their primary goals, are not sustainable and lead to the degradation of person and planet. This is because these goals know no limits. They are exhausting of resources and unresponsive to their harmful side-effects. What I am arguing for is a greater social conscience among scientists and a translation of that conscience into research that is relevant to food systems that have goals such as nourishment, fulfillment, flexibility, and sustainability (Hill, 1982; Hill and Ott, 1982; Hill, 1984a). I am also arguing for soil biologists and ecologists to speak out on these issues, and to broaden their area of interest to include the food system as a whole and its sustained operation over the long-term.

Let us now consider what a sustainable food system might entail and what contributions soil biologists can make towards its development and implementation.

In terms of material flows, a sustainable agriculture may be viewed as a production - consumption - recycle system. Most of the recycle process takes place within the soil in the form of organic matter decomposition. For sustainability to be achieved, inputs for decomposition must meet certain quantitative and qualitative criteria, *e.g.,* comprise a diverse range of substrates containing adequate amounts of major, minor and trace elements that, together with those from the earth's crust and the atmosphere, are capable of supporting plant growth. Substrates must also meet certain time, space and freedom from toxins, criteria. These criteria are more likely to be met in a multi-story polyculture that includes soil and ecosystem maintaining, as well as food producing, plants and animals, than in a uni-story row-crop monoculture (Mollison, 1979; Altieri, 1983; Todd and Todd, 1984). The agricultural task is the design and management of such systems and the soil zoology task is to describe the animals and processes that take place in the soil and, with others, to develop methods of soil management that can enhance the beneficial contributions of the soil fauna.

PROBLEM SOLVING WITHIN SUSTAINABLE AGROECOSYSTEMS

The approach to problems in such systems will probably differ radically from that employed today. Currently, agricultural problems usually receive attention only when their short-term economic consequences justify the required expenditures. Solutions tend to be confined to disciplines rather than multidisciplinary: entomologists dealing with insects, nematologists with nematodes, and so on.

An alternative approach, recognizing that the causes of problems often lie outside of the discipline concerned with their subject, and that prevention is usually less costly than cure, might channel the efforts and resources that currently are used to directly attack problems to a less easily defined, maintenance function for multifacetted agroecosystems. Thus, by working to optimize the functioning of the agroecosystem as a whole, problems within its parts would be minimized. Those that arise would be taken as indicators of malfunction, and efforts would be made to correct the malfunction. To be effective with this approach farmers would need to be more knowledgable and, "closer" to the agroecosystem, and supported more by society. Sociologically the process may be viewed as one of integration (of our species into the rest of the biosphere), balance (the maintenance of a sustainable relationship with the support environment) and feedback (paying close attention to the outcomes of our actions, recognizing their meaning and responding accordingly). Thus, attention is shifted from problem solving to system maintenance, the incidence of problems declining as systems approach optimal states. Problems that do arise are solved largely by removing the causes and strengthening the natural processes that normally prevent such problems from reaching crisis proportions (Hill, 1984b).

INDICATORS OF AGROECOSYSTEM DISTRESS

Recognition of undesirable processes often involves the identification of environmental stressors and the detection and measurement of their effects.

Because of the widespread and diverse nature of environmental stressors, and because of the complex nature of their interactions, there is a need to find ways to detect and measure their combined effects in a general way. Influenced by Selye's (1946) recognition of a "biological distress syndrome" in mammals, Rapport (1983) has proposed that we recognize a parallel "ecosystem distress syndrome" within environments. This concept is based on two important assumptions: (1), that different stressors give rise to certain similar symptoms (cf. Selye's "general adaptation syndrome"); and (2), that there are common indicators of distress that can be used in widely different ecosystems subject to different stressors.

The situation in mammals, however, is much more complicated than Selye has indicated. Randolph (1976), uses five levels to describe recognizable points along a continuum from healthy to severe illness within affected humans. One valuable insight from his observations is that at different times the symptoms present themselves in "up" (*e.g.*, hyperactive) and "down" (*e.g.*, depressed) states. While these are both recognized as being undesirable at the developed end of the spectrum, during the early stages of development the "up" condition (active, responsive, enthusiastic, ambitious, witty) may easily be regarded as desirable, its connection with the "down" condition (stuffy nose, occasional coughing and sneezing, skin disorders, gas, diarrhea, constipation, frequent urination and various eye and ear symptoms) not being recognized.

There may well be parallels to these observations with respect to the soil ecosystem (Hill, 1980). Thus, certain management practices may at first appear to be beneficial when measured in terms of their short-term influences on productivity. The negative effects of these practices are either hidden or not taken seriously until they reach crisis proportions, when it maybe too late to correct the situation.

The following indicators of environmental distress, identified by Rapport (1983) for the Great Lakes Ecosystem, are equally applicable to soil ecosystems:

1. Imbalance in nutrient concentrations (loss of some, accumulation of others)
2. Reduced species diversity
3. Replacement of longer lived by shorter lived species (adapted to transitory novel environments)
4. Replacement of larger by smaller life forms
5. Decline in biomass of macrofauna
6. Increase in amplitude of population fluctuations of key species.

Some of these were recently recognized by Andrén and Lagerlöf (1983) in their study of the effects of various agricultural practices on soil mesofauna.

One problem with these indicators is that they only provide an after-the-fact indication of distress. This limitation similarly applies to many specific indicators of environmental contamination, such as the accumulation of toxins up the food chain, and the incidence of reproductive failure among top predators (Rapport, 1983).

In addition to these indicators, we urgently need others that are able to provide us with an early warning of deteriorating conditions. For this, Rapport (1983) has proposed that we identify "indicator-integrator" organisms, species that are representative of their communities, are able to survive only in relatively unstressed ecosystems, and that are sensitive to a broad range of stressors.

Among soil invertebrates, predators within the air spaces and water film and highly mobile burrowers would seem likely candidates for this role. Karg (1968) has, long ago, stressed the value of using predatory soil mites as indicators, and Greenslade and Greenslade (1983) make a similar case for using ants. Predatory nematodes would probably serve a similar function within the water film. In fact, all soil animals are indicators of soil conditions. The problem is the interpretation of the information provided. Predators are particularly valued because their presence, population density, behaviour and body composition can provide, in a sense, a summation of most of the information provided separately by the organisms lower down in the food web. Among the non-predators, earthworms are already widely regarded by farmers as indicators of soil health, and have been successfully used as indicators of soil pollution by pesticides and industrial chemicals (Edwards, 1979, 1980). Ghilarov (1965) and Krivolutsky (1975) have proposed using soil fauna as indicators of soil type. The person with the greatest need for this "indicator information" is the farmer, and researchers should keep this in mind.

While it is essential that more work be done in this area, experience from other fields is not encouraging with respect to the ability of such studies, on their own, to bring about appropriate changes in agricultural practices. While most human populations are willing to support studies of the side-effects of their behaviour, it is rare to find changes in behaviours as a result of such studies. I have observed that most people only want to hear truths that validate their present lifestyles, that do not cause them to feel guilt, and that do not suggest that they should change their behaviour. It is often implied that, as scientists, we are more objective and more willing to be open to truths that disturb, but this has not been my observation. I believe that most of us conduct our science (and our lives), just as non-scientists conduct their lives, within a territory determined by our vulnerability to the truths that are likely to distress us. This implies that by increasing our vulnerability we are likely to improve our science. This involves opening-up more to our colleagues, to those in other disciplines, to non-scientists and, in a somewhat different sense, to the subjects of our research. The fact that this meeting has taken place, bringing together soil micromorphologists and soil zoologists from around the world, is a positive step in this direction.

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